Climate and Plague

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Climatic Impacts on Zoonotic/Vector-Borne Diseases

Four key factors influenced by climatic variables:

• Geographic distributions
• Population densities
• Infection prevalence
• Pathogen load, rate of development and transmissibility

(Gage et al. 2008, Mills, Gage, and Khan 2010)
Climate and Plague Transmission

Major pandemics preceded by significant climatic events:

• Justinian’s Plague
• Black Death
• Modern Pandemic

(Kausrud et al. 2010, Xu et al. 2011 and others)
Plague as a Model of Climate Effects on VBZDs

- Rodents respond rapidly to environmental changes
- Vector survival and reproduction affected
- Pathogen development and transmission affected by temperature (inverse relationship?)
- Geographic distribution of foci affected by climatic factors

### Effect of Temperature on Blocking of Fleas by *Yersinia pestis* and Mortality among Infected Fleas

<table>
<thead>
<tr>
<th>Yersinia pestis Strain</th>
<th>Percent of fleas blocked at given temperature</th>
<th>Percent flea mortality at given temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C</td>
<td>25°C</td>
</tr>
<tr>
<td>195-P-wt</td>
<td>32</td>
<td>13</td>
</tr>
</tbody>
</table>

**Note:** Most human cases occur when epizootics spillover to local human populations. Occurrence of epizootics often appear related to climatic variability
• Climate often linked to plague epizootics or epidemics
• Threshold rodent densities appear critical
• Widespread favorable conditions can increase rodent populations and result in large epizootics
• Drought can concentrate rodents in remaining favorable habitats and lead to more focal epizootics
• Effects vary from region to region

Regional and Local Climate Influences on Human Plague in the U.S. Ben Ari et al. (2008)

- Analyzed 56 year time series of human cases
- Variability in human plague activity across western U.S. could be explained largely by interactions between
  - Previous plague levels
  - Above normal temperatures
  - Pacific Decadal Oscillation
- Warmer and wetter climate led to increased human cases
- Did not initially see ENSO effect
Human Plague Occurrence Influenced by Tropical and North Pacific Ocean Climatic Variability (Ben Ari et al. 2011)

• Used wavelet analysis to examine relationships between human plague occurrence and climate

• Human plague occurrence in western US influenced by interaction of ENSO and PDO

Figure Legend
A. Total density-adjusted human cases
B. PDO Index (March value)
C. ENSO (Sea surface temperatures for Nino 3-4 region)
D. Late winter-spring precipitation
E. Anomaly of yearly maximum NDVI
F. Average number days above 37° C
G. Average minimum temperature
Row A shows composite late-winter spring precipitation anomalies for years with significant:

- Negative PDO and La Nina (left panel) events (very dry) or
- Positive PDO and El Nino events (much wetter than normal)

Row B shows composite NDVI anomalies for years with significant

- Negative PDO and La Nina (left panel) events (“brown down”) or
- Positive PDO and El Nino events (“green up”)
Climate and Plague Risk in West Nile Region

Plague risk greatest above 1,300 m and in areas that
- Are wetter
- Are cooler
- Exhibit more bare soil at certain times of the year

Human plague associated with
- Dry season rainfall (negative)
- Rainfall prior to plague season (positive)

Nile grass rat (Arvicanthis niloticus) abundance associated with
- 6 month-lagged precipitation (negative)
- Current monthly temperatures (positive)

Shrew (Crocidura sp.) abundance associated with
- 3 month-lagged precipitation (positive)
- Current temperatures (negative)

Abundance of both species positively correlated with millet and maize harvests (Moore et al. 2012, 2015)
How Does Temperature Affect Transmission of \textit{Y. pestis}?

- High temperatures can decrease flea survival
- Affects biofilm formation
  - Biofilm in blockages breaks down above 27.5°C
  - Infection can be lost above this temperature
  - Some evidence spread of plague outbreaks decreases above this temperature (Vietnam - Cavanaugh and Marshall 1972)
- Plague transmission experiments typically done at 21°C-23°C
- How do lower temperatures affect transmission?
  - Plague bacteria grow faster at cold temperatures
  - Transmission rates increase at low temperatures for \textit{O. montana} (Williams et al. 2013)
  - Implications for seasonality and focality of plague
Effect of Temperature on Growth of \textit{Y. pestis} in \textit{O. montana} fleas
(Williams et al. 2013)
Flea Transmission to Mice by Incubation Temperature
(Williams et al. 2013)

Percent Transmission to Mice
6°C - 46.03 (29/63)
10°C - 71.42 (45/63)
15°C - 66.67 (42/63)
23°C - 25.40 (16/63)

- No transmission events observed on Days 3 and 4 p.i. at 23°C
- 100% transmission on Days 10, 14, and 17 p.i. at 15°C
Effects of Temperature on Transmission of *Yersinia pestis* by Fleas

**Summary**

- Low temperatures favors growth of *Y. pestis* in fleas
- *X. cheopis* fleas apparently succumb to overwhelming *Y. pestis* infection at low temperatures (10°C)
- *O. montana* (poor blocker) transmits more efficiently at low temperatures
- Can other poorly blocking fleas transmit efficiently at low temperatures?
- *Y. pestis’* closest relative and ancestor (*Y. pseudotuberculosis*) can survive outside hosts at low temperatures in shed fecal material
- Implications for focality in temperate and tropical regions?

Note that *X. cheopis* fleas did not survive past day 14 at 10°C.

Bacterial Loads in *X. cheopis* held at different temperatures

(Schotthoefer et al. 2011)
Plague and Climate Change

• Nakazawa et al. (VBZD 2008) evaluated spatial patterns of plague transmission using four different general circulation models of project climate change

• Concluded that some shifting of transmission sites would occur but changes will be subtle with general northward movement of areas of high transmission

• Is this realistic and does it apply to other plague foci around the world?
The End